CHARLES DARWIN UNIVERSITY

Family Name	
Given Names	
Student Number	
Teaching Period	Semester 1, 2017

FINAL EXAMINATION	**DURATION**
ENG364 – Materials Engineering	Reading Time: **10** minutes Writing Time: **180** minutes

INSTRUCTIONS TO CANDIDATES

The examination has **2** sections. Both sections must be answered.

Section A: Suggested Time:	The section is worth 20%. This section is mandatory. There are no choices. 35 minutes
Section B: Suggested Time:	This section is worth 80%. Answer any 5 of the 7 questions. Each question is worth 16 marks. In each question, part A is worth 6 marks and part B is worth 10 marks. 145 minutes

EXAM CONDITIONS

<u>You may begin writing from the commencement of the examination session.</u> The reading time indicated above is provided as a guide only.

This is a CLOSED BOOK examination

Any non-programmable calculator is permitted

No handwritten notes are permitted

No dictionaries are permitted

ADDITIONAL AUTHORISED MATERIALS	**EXAMINATION MATERIALS TO BE SUPPLIED**
No additional printed material is permitted	1 x 20 Page Book Formula Sheet/s

THIS EXAMINATION IS PRINTED DOUBLE-SIDED.

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Section A

The section is worth 20%. This section is mandatory. There are no choices.

A1.

You are required to select a suitable material for a large reflecting mirror of a telescope. The reflecting surface should be about 5.1m in diameter. The deflection of the reflecting surface should be very low, about 0.05μm. Select a suitable material for the reflecting mirror from Table 1. You must consider all aspects of design in order to keep the deflection and should be of low maintenance. You can assume that the mirror is simply supported and it deflects due to its own weight.

Deflection of the mirror is given by the formula $\delta = \frac{0.67}{\pi}\frac{Mga^2}{Et^3}$ (t, thickness, is only the variable that can be changed). E is the Young's modulus, g is acceleration due to gravity, a is the radius of the mirror and M is the mass of the mirror.

A schematic of the reflecting mirror is given in Fig.1.

Describe your thoughts in a detailed manner on selecting alternative materials.

Table 1 Data for possible materials for the reflecting mirror

	Material	**ρ (Mgm^{-3})**	**E (GNm^{-2})**
1	Steel	7.8	200
2	Concrete	2.5	47
3	Aluminium alloy	2.7	69
4	Glass	2.5	69
5	Titanium	4.5	120
6	GFRP – quasi isotropic	2.0	15
7	CFRP – quasi isotropic	1.5	70

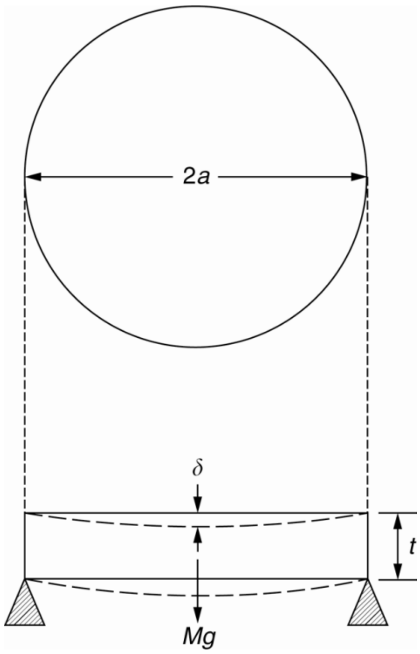

Fig.1 The elastic deflection of a telescope mirror under its own weight.

Ref: M F Ashby & D RH Jones Engineering Materials 1, Fourth edition, Elsevier, 2012.

Section B

This section is worth 80%. Answer any 5 of the 7 questions. Each question is worth 16 marks. In each question, part A is worth 6 marks and part B is worth 10 marks.

Question B1

A. In selecting materials and designing structures, what are the different ways in which the deflection of a structure/component can be kept as low as possible? Explain.

B. A composite material consists of parallel fibres of Young's modulus E_f ina matrix of Young's modulus, E_m. The volume fraction of fibres is V_f. Derive an expression for E_c Young's modulus of the composite along the direction of fibres in terms of E_f, E_m and V_f. Obtain an analogous expression for the density of the composite, ρ_c. Using the parameters given in Table 2, find ρ_c and E_c for the following composites

a. Carbon fibre-epoxy resin ($V_f = 0.3$)
b. Glass fibre-polyester resin ($V_f = 0.4$)
c. Steel-concrete ($V_f = 0.03$)

Table 2 Materials for composites

Material	**Density (g/cm^3)**	**E (GPa)**
Steel	7.8	200
Carbon fibre	1.9	390
Glass fibre	2.55	72
Epoxy and polyester resin	1.15	3
Concrete	2.4	45

Question B2

A. What is the significance of hardness tests and their application to design of structures? What are the limitations?

B. You are required to select a suitable material for springs with the data given in Table 3. In order to do this, derive a suitable parameter. The material selected must not undergo any plastic deformation when in use as a spring. The primary function of a spring is that of storing elastic energy and- when required- releasing it again. Consider an axial spring configuration for the selection of materials. Discuss your selection.

Table 3 Materials for springs

Material	**E(GNm^{-2})**	**σ_y(MNm^{-2})**
Brass (cold rolled)	120	638
Bronze (cold rolled)		640
Beryllium Copper		1380
Spring steel	200	1300
Stainless Steel (cold rolled)		1000
Nimonic (high temperature spring)		614

Question B3

A. Describe the parameters that describe ductility. Describe why ductility is important in structural materials.

B. Draw a schematic diagram to show a tensile test curve for a ductile metal and mark the following parameters:
- Elastic region
- Plastic region
- 0.1% proof strength
- Tensile strength
- Plastic strain at fracture
- Elastic energy at fracture
- Young's Modulus

Question B4

A. How can charpy impact test be used to select materials for low temperature applications? Explain with examples.

B. A cylindrical pressure vessel in an ammonia plant was 7m long, had an internal diameter of 1m and had a wall thickness of 62mm. The vessel was subjected to an internal pressure of 35.3MPa.

After 16 years in service the vessel exploded into a large number of fragments. Semicircular “thumbnail” cracks typically 6mm deep, were found at the inner surface of the vessel; they had initiated at the edges of a series of fillet welds used to attach internal fittings to the vessel wall (Y=1.12x0.64). The gas in the vessel contained 58% hydrogen and cracks were blamed on hydrogen cracking. Tests on samples of the steel gave a value of Kc of about 40MNm$^{-3/2}$. You should assume that there is a residual tensile stress of 100MPa at the welds in addition to the hoop stress.

   a. Account for the failure using fracture mechanics.
   b. Describe how tensile residual stress develops in welds.

Question B5

A. Describe the usefulness and limitations of Pourbaix diagrams.

The Pourbaix diagram for iron is given in Fig.2. At what potential should iron be held to be protected from corrosion when it is surrounded by a neutral solution (pH 7)?

If the same material was immersed in an acidic medium (pH 4) at potential 0.0V vs SHE, what would be the corrosion state of the structure?

At the potential (-0.44V vs SHE) if the pH of the environment surrounding the steel structure is increased to 11 (by pouring concrete), what will be the corrosion state of the structure?

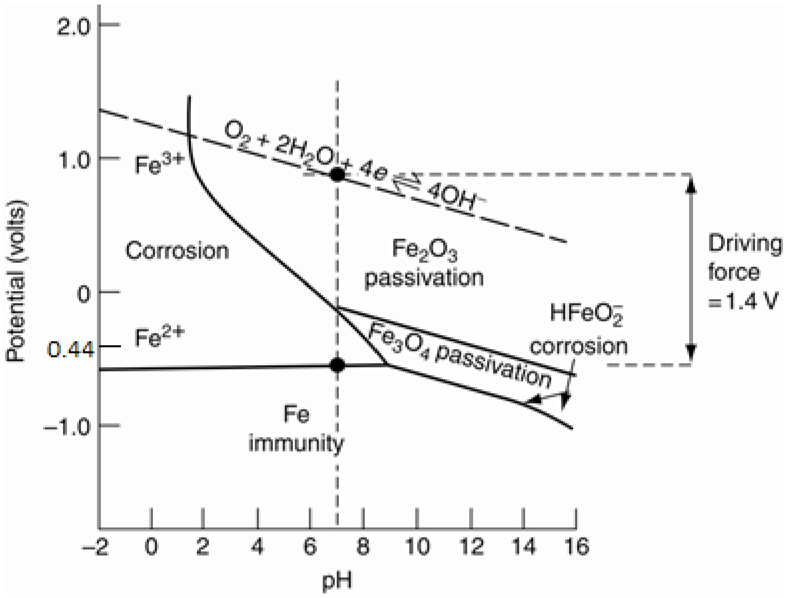

Fig.2 Pourbaix diagram for iron

Ref: M F Ashby & D RH Jones Engineering Materials 1, Fourth edition, Elsevier, 2012.

B. Answer all of the following questions

i. Describe an expression for the corrosion rate of materials. Describe the importance of this expression to the design of structures. Name the different methods of protecting structures from uniform corrosion.

ii. Consider a copper-zinc corrosion couple. If the current density at the copper cathode is 0.05A/cm^2, calculate the weight loss of zinc per hour if (a) the copper area is 100 cm^2 and the zinc anode area is 1cm^2 and (b) the copper cathode area is 1cm^2 and the zinc anode area is 100cm^2. Hint: The current density in the cell is the same everywhere in the corrosion couple and zinc loses 2 electrons for each mole of zinc.

iii. Explain the importance of anodising treatment for aluminium.

iv. In steel reinforced concrete structures near water the steel reinforcement corrodes and the concrete surrounding generally cracks. Why does this happen and how can the reinforced concrete be repaired in some cases?

Question B6

A. Explain the micro-mechanisms of fracture in ductile and brittle metals. Why a composite made of two brittle materials is tougher than the individual components?

B. A large component is made of a steel for which Kc = 54MNm$^{-3/2}$. Non-destructive testing by ultrasonic methods shows the component contains on surface cracks upto a=2mm deep. Laboratory tests show that the crack growth rate under cyclic loading is given by

$$\frac{da}{dN} = A(\Delta K)^3$$

where a = 6x10^{-12}m(MNm$^{-3/2}$)^3. The component is subjected to an alternating stress range of $\Delta\sigma$ = 180MNm^{-2}. Given that $\Delta K = Y\Delta\sigma(\pi a)^{½}$, estimate the number of cycles to failure. Y=1.12.

Question B7

A. Describe in detail how the chemical composition of Nickel-based superalloys is designed to resist creep when used in turbines blade.

B. Answer all the following questions.
   i. Describe diffusion and dislocation creep mechanisms in metals and ceramics.

   ii. Describe the fabrication methods for producing turbine blades in order to resist creep?

   iii. Why are some materials such as aluminium and high Ni steels used for cryogenic applications? Why are plain carbon steels not used in cryogenic applications?

   iv. Describe what is creep in high temperature components and explain why ceramics and some metals resist creep better.